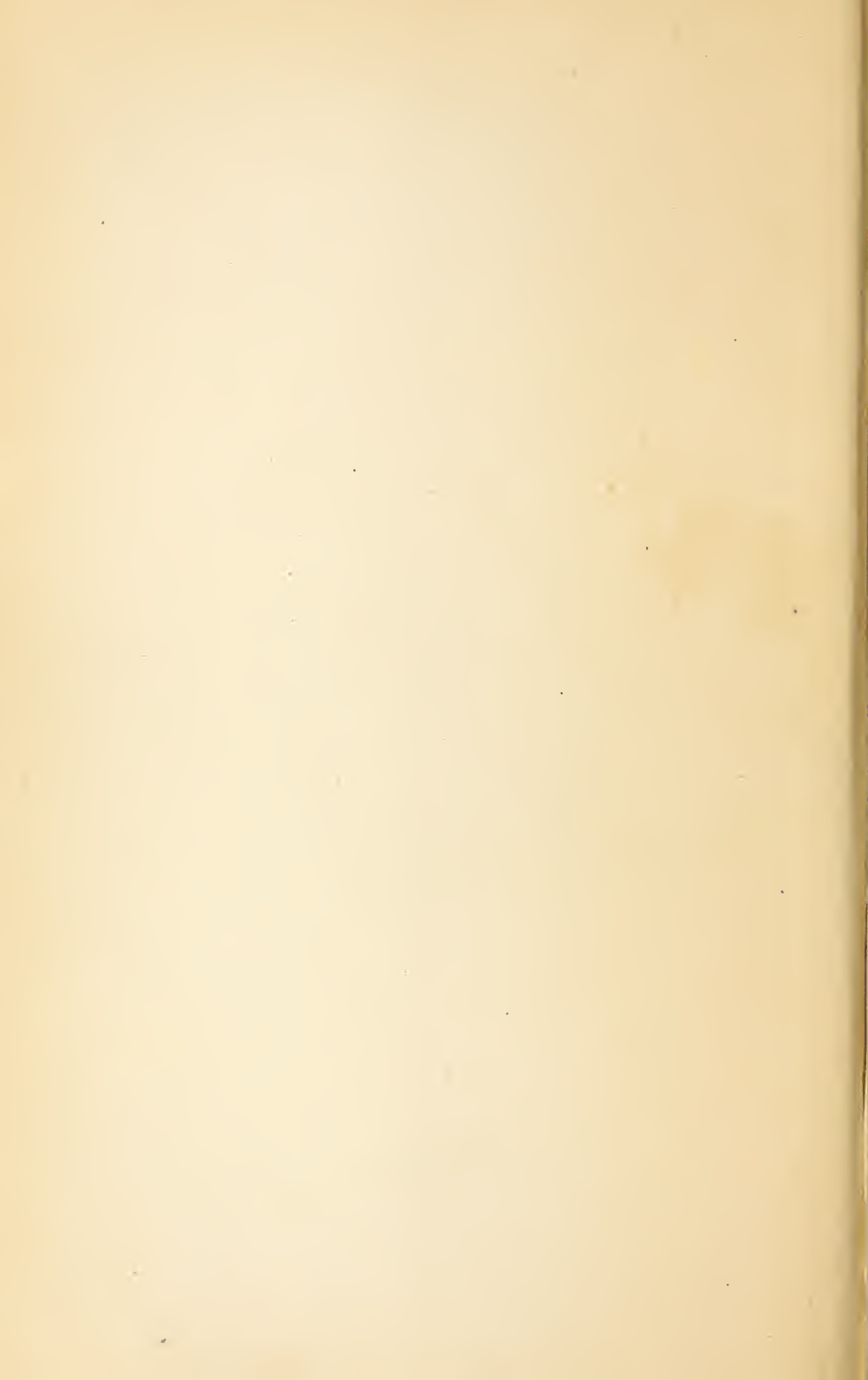






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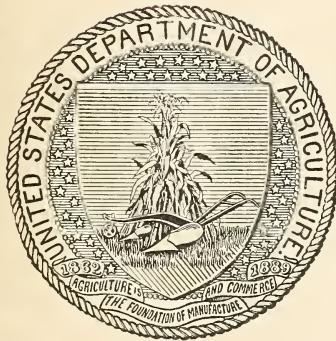
U. S. DEPARTMENT OF AGRICULTURE,  
BUREAU OF SOILS—BULLETIN No. 54.  
MILTON WHITNEY, Chief.

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# THE MINERAL COMPOSITION OF SOIL PARTICLES.

BY

G. H. FAILYER, J. G. SMITH, AND H. R. WADE.



WASHINGTON:  
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1908.

## LETTER OF TRANSMITTAL.

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U. S. DEPARTMENT OF AGRICULTURE,  
BUREAU OF SOILS.

*Washington, D. C., July 23, 1908.*

SIR: I have the honor to transmit the manuscript of an article entitled The Mineral Composition of Soil Particles, by G. H. Failyer, J. G. Smith, and H. R. Wade, and to recommend that it be published as Bulletin No. 54 of the Bureau of Soils.

Very respectfully,

MILTON WHITNEY,  
*Chief of Bureau.*

Hon. JAMES WILSON,  
*Secretary of Agriculture.*



## PREFACE.

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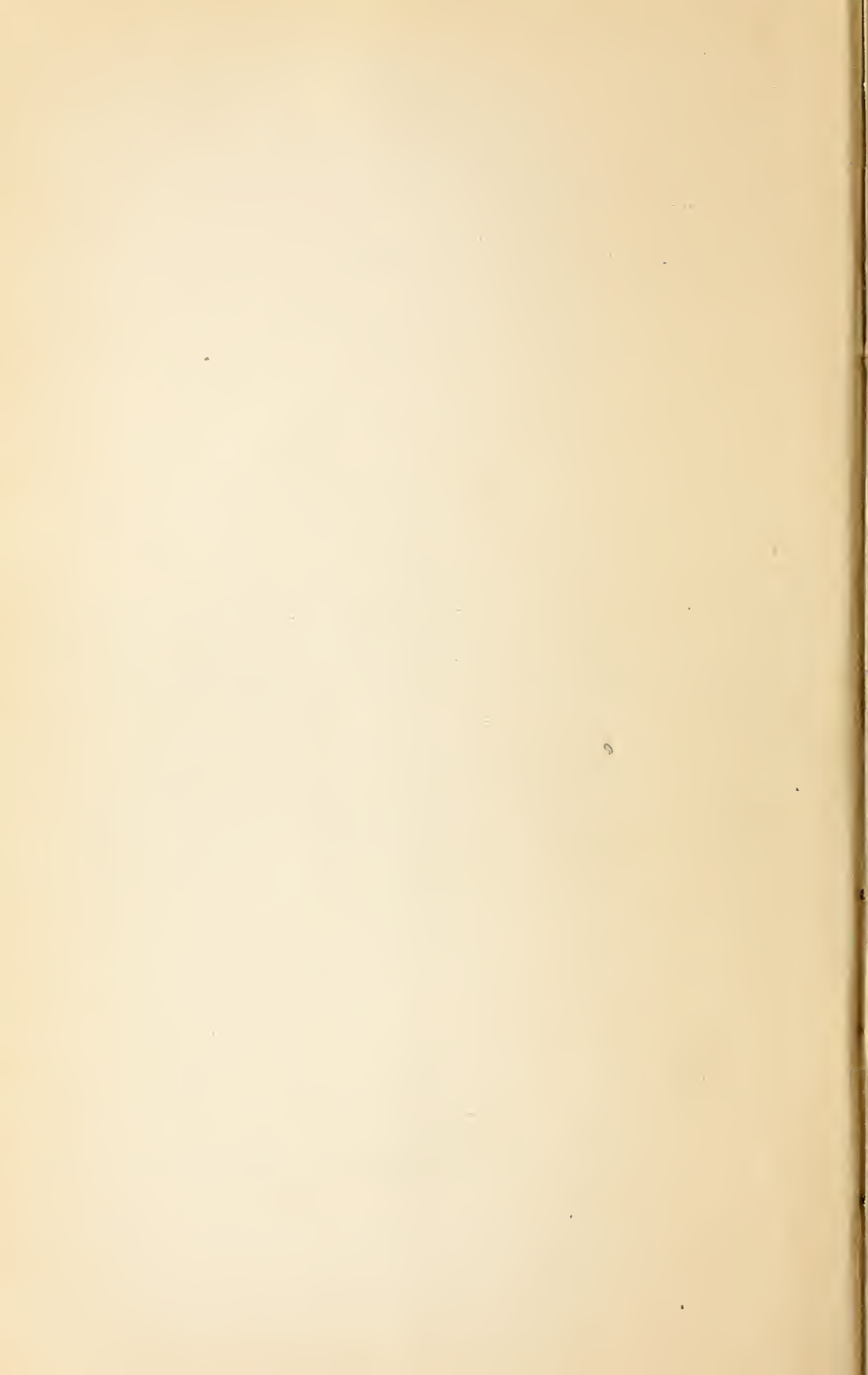
It is now generally understood that the mineral components of soils fall into two general classes. The first class comprises the common rock-forming minerals. It is generally the case, however, that a soil appears to be much more complex and to contain many more different minerals than any given rock. This is due in part to the fact that in the rock a certain few minerals which characterize that particular rock predominate to such an extent as to mask the other minerals which may be present. It is also due in part to the fact that the transportation of soil material from point to point, often to great distances, by wind and water and other agencies, produces a very complex mineral mixture, so that in almost any soil all or nearly all of the common rock-forming minerals can be found. It is very probable also that many minerals form in the soil. The various mineral fragments can be found to a greater or less extent through all the various sized soil particles, but in general, as might be anticipated from their origin, the finer the particles of the soil the more complex is the mineral mixture.

The second class of mineral components in the soil consists of decomposition products derived from the first class by the action of water and other weathering agencies of one kind or another. It is common knowledge that of these substances the silica, as quartz, tends to accumulate in the coarser grades of soil particles and ferruginous material in the finer grades. The distribution of the other products is not so obvious, although of the first importance for both theoretical and practical handling of soil problems.

The existing literature on this subject is meager and unsatisfactory. The tedious and difficult analytical operations involved have undoubtedly deterred investigators hitherto; but the importance of the subject in itself and as a connecting link in the larger problem of the mineral chemistry of the soil, which is being investigated by this Bureau, has led Mr. Failyer, with Messrs. Smith and Wade, to study the chemical composition of the soil separates of a number of soils, covering all the important agricultural areas of the United States. The mineralogical composition of these same separates is still under investigation.

The conclusions summarized at the end of the present bulletin may be taken safely as applying to soils generally, and mark another positive step forward in our knowledge of soils.

FRANK K. CAMERON.

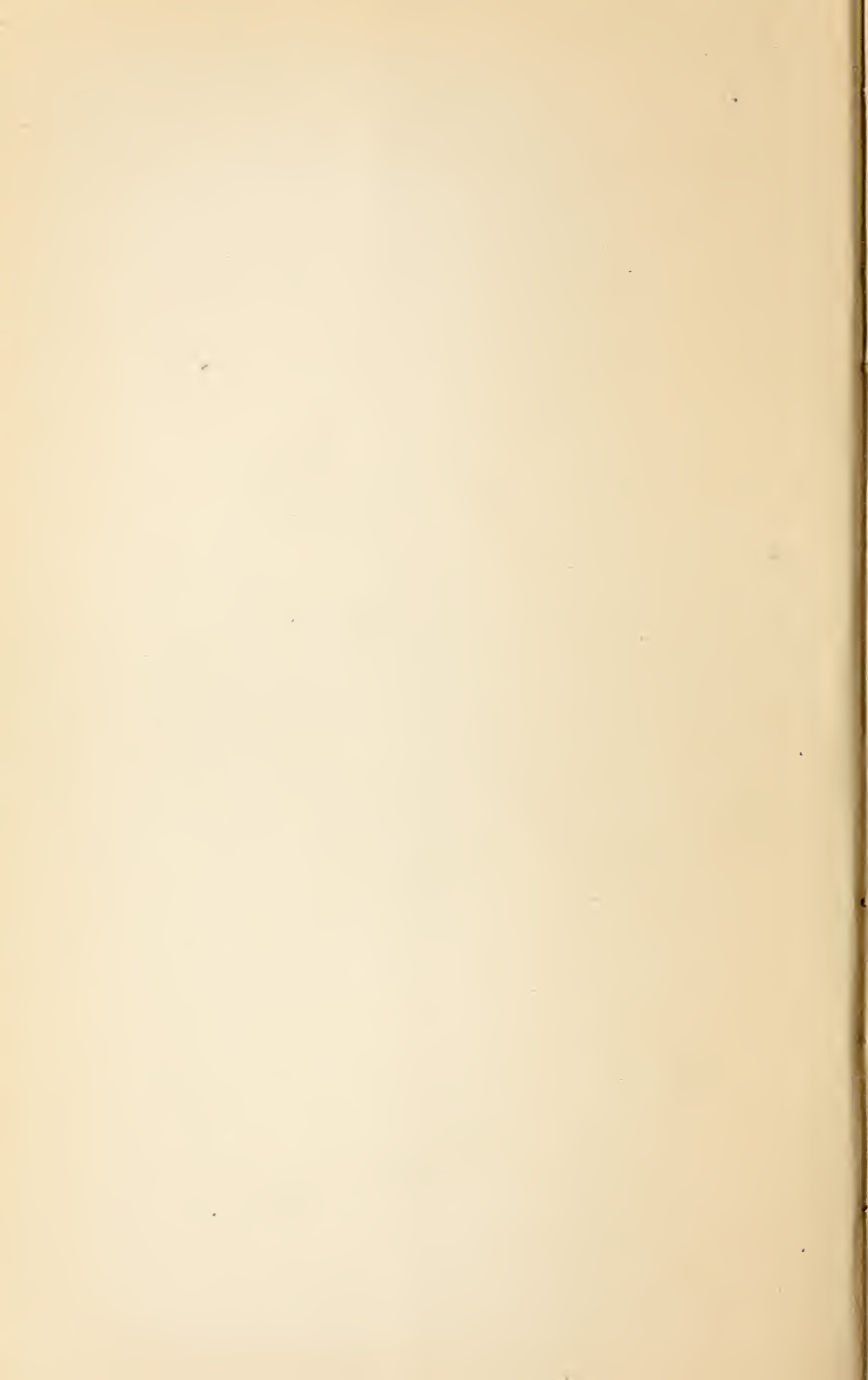




## CONTENTS.

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	Page.
Introduction.....	7
Selection of soil samples.....	15
Soils of the Coastal Plains.....	16
Soils from crystalline and metamorphic rocks.....	19
Soils of glacial origin.....	21
Soils derived from limestones and shales.....	25
Soils of the arid region.....	27
Comparison of the groups of soils.....	29
Rocks, soils, and soil separates.....	33
Summary.....	35



# THE MINERAL COMPOSITION OF SOIL PARTICLES.

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## INTRODUCTION.

As is well known, soils are made up of mineral particles of many different sizes, and the relative proportions of the different sized particles have a most important influence on the physical properties of the soil and its adaptability to the growth of various kinds of crops. Therefore, in the mapping of soils by the Bureau, mechanical analyses of many type samples are made. By sedimentation, assisted by a centrifuge, soils are separated into arbitrary mechanical components called clay, silt, and sand. The latter is separated by sifting into five grades. As used by the Bureau, clay comprehends particles having a diameter of 0.005 mm. or less; silt includes particles whose diameters range from 0.005 to 0.05 mm.; very fine sand, particles from 0.05 to 0.1 mm.; fine sand 0.1 to 0.25 mm.; medium sand, 0.25 to 0.5 mm.; coarse sand, 0.5 to 1 mm.; very coarse sand, 1 to 2 mm.

It is a matter of interest and importance to know how these separates compare in their content of the important mineral plant-food constituents. For instance, whether phosphorus, potassium, and calcium be uniformly distributed through the sand, the silt, and the clay, or whether they be concentrated in one or more of these separates; and whether different classes and types of soils differ in this respect.

Another matter of interest is the influence of the manner of the formation of the soil and of climate upon the distribution of the several mineral nutrients. The past history of the soil greatly affects its mechanical and mineralogical composition. How it will affect the distribution of the plant-food constituents is not always obvious.

For some time investigators have recognized that the groups of various sized particles of a soil may differ in chemical composition. Considerable attention has been given to certain phases of the subject; but it has not as a whole received the detailed study that it deserves. Much of the analytical work that has been done upon the mechanical separates of soils has been by treatment with some conventional strength of hydrochloric acid. Such work is a study of solution and not of ultimate composition.

Apparently Loughridge<sup>a</sup> was the first to make any study of the chemical composition of the mechanical elements of a soil. By means

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<sup>a</sup> Am. Jour. Sci., 7, 17 (1874).

of Hilgard's churn elutriator he prepared mechanical separates of a loam upland subsoil from Mississippi. The separates were extracted by five days' digestion in hydrochloric acid of 1.115 specific gravity and the solution analyzed. Larger proportions of potash, magnesia, iron, alumina, and silica were found in the extract of the finer portions than in that of the coarser. The lime was irregular and the soda and sulphuric acid somewhat uncertain.

Orth<sup>a</sup> made mechanical separations of samples of a soil taken at four depths. These samples consisted of the surface soil to a depth of about 8 inches—loamy sand; a layer of subsoil about 16 inches thick—loamy sand; a 16-inch layer of loam below the preceding, and a thick layer of marly loam under all of these. Chemical analyses, by decomposition with hydrofluoric acid, were made of each of these samples and of the particles of each under 0.01 mm. in diameter. The whole soil of each layer contained a greater percentage of silica than did the part less than 0.01 mm., while the latter contained a higher percentage of potash, lime, magnesia, soda, iron, alumina, and phosphoric acid. Orth does not make these comparisons, but a recalculation of his tabulated figures makes the comparison possible. It should be observed that this is not a direct comparison of the composition of the coarse with that of the fine particles. The whole soil is compared with its finest part. Indirectly, of course, a comparison is made of the coarser with the finer portions of this one soil and its subsoil.

Schneider<sup>b</sup> studied a residual soil from the Rockland Ridge, near The Dalles, on the Columbia River, Washington. The rock whose disintegration formed the soil is said to be an augite andesite, its principal constituents being "plagioclase, augite, apatite, magnetite, undifferentiated glass."

The soil was subjected to mechanical analysis by Hilgard's well-known method. For purposes of analysis, four groups were made of the sediments prepared from the fine earth—the part less than 0.6 mm. diameter. One group included particles of diameters between 0.5 and 0.1 mm.; another, particles between 0.1 and 0.01 mm.; another, those between 0.01 and 0.001 mm., and the last portion, particles less than 0.001 mm. This last fraction was called "clay."

Both fusion and acid digestion methods were used in analyzing these sediments, but as indicated in Table I, not all the analyses were carried to completion.

Table I gives Schneider's results calculated to water-free and organic-matter-free substance. The dimensions of the fractions are derived from Hilgard's "Table of diameters and hydraulic values of sediments."<sup>c</sup>

<sup>a</sup> Ber., 15, 3028 (1882).

<sup>b</sup> Am. Jour. Sci., 36, 236 (1888).

<sup>c</sup> Am. Jour. Sci., 6, 337 (1873).

The author points out that the percentages of "alkalis and alkaline earths extracted by the hydrochloric acid decrease in the fractions almost proportionately to the decrease of total percentages obtained in the analysis by fusion."

From an inspection of Table I it is seen that the phosphoric acid and the magnesia are irregularly distributed among the sediments; that the lime decreases with the size of the particles; and that the potash, so far as given, increases as the particles decrease in size.

TABLE I.—*Partial composition of the separates of a soil analyzed by Schneider.*

Grade of material.	By fusion.			By acid digestion.			
	CaO	MgO	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	CaO	MgO	K <sub>2</sub> O
	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Particles 0.5 to 0.1 mm.....	6.57	2.60	1.54	0.14	3.02	1.06	0.32
Particles 0.1 to 0.01 mm.....	.....	.....	.....	.18	2.60	.82	.38
Particles 0.01 to 0.001 mm.....	3.32	1.86	1.90	.46	2.23	1.56	.66
"Clay," less than 0.001 mm.....	.51	1.93	.....	.14	.21	1.43	.....

In studying the changes in composition when rocks weather to soils Merrill <sup>a</sup> has analyzed a soil and the "silt" separated from it. Under silt are included particles 0.1 mm. and less in diameter. This silt contained larger percentages of potash, lime, and magnesia than did the soil.

R. Sachsse <sup>b</sup> analyzed the fine earth of five soils and also the portions of these soils carried over by a stream of water of 0.2 mm. velocity. A comparison of the tabulated results shows great irregularity in the distribution of the elements. The lime, potash, and alumina are proportionately more abundant in the very fine particles than in the soil as a whole. The proportion of iron, magnesia, and soda is greater in the finer parts of some of the soils; in others the reverse is true. The phosphoric acid in the portions carried by the 0.2 mm. stream is not given. In this case, as before, the whole soil is compared with one of its parts.

Meyer <sup>c</sup> likewise compared the composition of the whole soil with that of its finer parts. Twenty-six soils differing much in physical character were used in his work. For analysis and comparison, three samples were prepared from each soil. One consisted of the whole soil, excluding gravel above 5 mm. in diameter. It was pulverized in a mortar to pass through a 0.5 mm. sieve, for treatment with acid as described below. Another sample was the "fine earth." It was obtained from a portion of the original soil by sifting, the part pass-

<sup>a</sup> Bul. Geol. Soc. Am., 6, 323 (1895).

<sup>b</sup> Chem. Centr.-Blatt., 66, 1, 752 (1895). The original publication (Geologische Spezialkarte der Königreichs Sachsen, Sektion Lommatzsch-Leuben) is not accessible to us.

<sup>c</sup> Landw. Jahrb., 29, 913 (1900).



ing through a 0.24 mm. sieve being taken for analysis. The third sample was the clay or dust (staub). It was separated from another portion of the original soil by sifting, and consisted of particles not greater than 0.11 mm. in diameter. Since the finer grades of soil particles are found in all three samples thus prepared and the coarser ones are not, any differences in composition of the samples must be due to differences between the fine and the coarse particles. These samples were digested in hydrochloric acid for three hours at 100° C. and the extract analyzed. With very few exceptions he found greater percentages of lime, magnesia, iron and alumina, and phosphoric and sulphuric acids, in the extracts of the "fine earth" than in those of the whole soil, and greater percentages of these substances in the extracts of the "dust" than in those of the "fine earth." No determinations were made of the potash in the samples. Since only the substances dissolved by the acid were determined, this is more a solubility study than one of composition.

Tolman,<sup>a</sup> working on two soils from the arid region, found a greater degree of solubility in the finer particles, but the acid (hydrochloric acid of 1.115 sp. gr.) extracted notable amounts from all of the separates, even those of 2 mm. diameter. A higher percentage of potash, soda, magnesia, iron, alumina, and phosphoric acid was found in the solutions of the finer portions. The lime varied, but was an approximately constant constituent of the separates. He compared his results with those obtained by Loughridge and found, as might be anticipated, that much greater proportions of the soluble substances occur in the coarser grains of the arid soils than in those of like size in the humid soil.

Headden,<sup>b</sup> working upon a granitic soil on the station grounds, took a sample 10 inches deep and separated the fine earth (the portion passing through a sieve of 1 millimeter mesh) by beaker elutriation into 6 components. Complete chemical analyses were made of the "fine sand," particles 0.25 to 0.05 mm. in diameter, the "silt," 0.05 to 0.01 mm., the "dust," 0.01 to 0.001 mm., and the "clay," less than 0.001 mm. It is pointed out that the separates differ decidedly in composition, and that "there is an accumulation of potash in the finer portions of the soil, and a diminution of the silicic acid."

Westermann<sup>c</sup> investigated the relations of the "clay" (ler) content of certain Danish soils to their content of the several plant food constituents. He made mechanical analyses of 100 soils from eighteen counties well distributed over Denmark. Eighteen of these soils, varying in clay content from high to low, were digested forty-eight hours at 19° C. in 30 per cent hydrochloric acid, and the solu-

<sup>a</sup> Rept. Cal. Agr. Expt. Sta., 1898-1901, Part I, p. 33.

<sup>b</sup> Bul. 65, Colo. Agr. Exp. Sta. (1901), p. 19.

<sup>c</sup> Undersøgelser over Typer af danske Jorder, Copenhagen, 1902.



tions analyzed. He finds no constant relation between the content of phosphoric or sulphuric acids extracted and of "clay;" the relation between the content of potash and of "clay" is close; there is a general similarity in the content of "clay" and of lime, magnesia, and iron, but there are important individual departures from the rule.

Bagger<sup>a</sup> studied the relation of the soluble potash content of soils to the impalpable matter they contain, using results of other workers as well as some of his own. In some of the published results of analyses he finds that soils containing the more clayey substances are richer in soluble potash; in others the reverse is true. Bagger himself examined eight soils of known history. A micaceous sandy soil containing little "clay" (abgeschlammte teile) was rich in potash soluble in concentrated hydrochloric acid, while heavy loams contained much "clay" and little potash. His general conclusion from his study of soils is that the potash content of the soil bears no definite relation to its mechanical composition, thus combating a view held by several agricultural writers. Potash is the only constituent considered by this author. He compares the potash extracted from the soils as a whole with that from the finer particles, and does not determine the potash in the mechanical separates themselves.

Schloesing<sup>b</sup> selected four soils that varied from very sandy to very clayey, and separated these into their mechanical components by a method of sedimentation, which is given. These separates were boiled with hydrochloric acid and the iron and phosphoric acid in the extracts determined. In each of the soils the iron and the phosphoric acid increased as the size of the physical elements decreased. The iron and the phosphoric acid contained in the undissolved mineral grains would not be determined by this treatment. Schloesing<sup>c</sup> also compares the separates of two subsoils as to their content of carbon. The soils above the subsoils are rich in organic matter. One of the subsoils is highly calcareous, the other nearly free from lime. Schloesing found that the finer portions of these subsoils are the richer in carbon. He is of the opinion that soil grains are coated with the various substances that have gone into solution in soils and have separated out again. Since the surface of small particles is greater compared to their mass than is the case with larger ones, these coatings would form a higher percentage of the finer separates, even if they be of the same thickness.

Rudzinski,<sup>d</sup> in the course of experiments in the growth of plants in the mechanical elements of soils, prepared separates of a clayey cher-

<sup>a</sup> Inaug. Diss., Albertus-Universitat, Königsberg, 1902.

<sup>b</sup> Compt. rend., **134**, 631 (1902).

<sup>c</sup> Compt. rend., **135**, 601 (1902).

<sup>d</sup> Izv. Moscow Selsk. Khoz. Inst. (Ann. Inst. Agron., Moscow.), IX, No. 2, p. 172 (1903). (Expt. Sta. Rec. XVI, 345, 1904.)

nozom (black earth), a peaty clay, and a podzol soil (an ashy soil composed largely of very fine sand). He concludes from his chemical examination of the separates that the content of potash and of phosphoric acid in the mechanical elements of the soils investigated decrease with the increase of their size, and that the like separates from soils of like geological origin even are unlike in their chemical composition.

Mazurenko <sup>a</sup> made mechanical analyses of two strikingly different soils, a loess and a podzol. The data show that in the separates of both soils the silica decreased and the other elements increased as the size of the particles decreased.

Dumont <sup>b</sup> compares the distribution of potash among the separates of two soils about equally rich in this substance, but very different as to origin and manner of formation. One was a fine-grained soil from an experimental field at Grignon, the other a coarse, sandy granitic soil from Creuse. They were separated into different sized particles by the method of Schloesing, the separates decomposed by hydrofluoric acid, and analyzed by usual methods.

Table II shows the percentage of potash in the separates, the potash of each separate expressed as percentage of the whole soil, and the percentage distribution of the potash of the soil among the separates.

TABLE II.—Potash content of soil separates according to Dumont.

Grade of particles.	Potash, per cent of separate.		Potash, per cent of soil.		Per cent of potash of soil in separate.	
	Soil of Grignon.	Soil of Creuse.	Soil of Grignon.	Soil of Creuse.	Soil of Grignon.	Soil of Creuse.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Coarse sand.....	0.864	1.33	0.148	0.605	16.55	70.93
Fine sand.....	.992	.58	.588	.225	65.78	26.37
Clay.....	.940	.51	.158	.023	17.67	2.70
			.894	.853		

It is obvious that although these soils contain about the same proportion of potassium, the element is very differently distributed in their mechanical components. The separates of the Grignon soils are about equally rich in potash, while the sand of the soil of Creuse is nearly three times as rich as the clay. As pointed out by Dumont, five-sixths of the total potash of one soil is contained in its finer particles, whereas in the other, on the contrary, seven-tenths of the potash of the soil is in the coarse sand.

Hall <sup>c</sup> prepared separates of the Rothamsted soils by sedimentation. Composites were prepared by mixing the sediments of like grade derived from the several soils. The partial composition of

<sup>a</sup> Inaug. Diss., Munich; Abs. in Zhur. Opuitn. Agron. (Jour. Expt. Landw.), V, No. 1, p. 73 (1904). (Expt. Sta. Rec. XVI, 344, 1904.)

<sup>b</sup> Compt. rend., 138, 215 (1904).

<sup>c</sup> Jour. Chem. Soc., 85, 950 (1904).

these mixed sediments, as given by Hall, shows that the percentage of silica decreases and that of the alumina and the iron increases as the size of the sediments decreases—an observation confirmed by work in this laboratory for soils in general.

Puchner,<sup>a</sup> in an article on the distribution of nutrients in the separates of the soil, describes his work upon three soils differing widely in physical character and in geological origin.

Soil No. 1 was a heavy loam; No. 2, a silty soil (loessial); No. 3, a coarse sandy soil from gneiss. These soils were resolved into their mechanical components, four divisions being made of the particles less than 0.25 mm. in diameter. Complete analyses were made of these finer separates. The medium and coarse sands not being analyzed, no comparison of the composition of these with the finer portions can be made.

The composition of the finer separates of the three soils is given in Table III. Table IV gives the content of the elements in the several separates calculated to percentages of the soil.

TABLE III.—*Composition of the mechanical separates analyzed by Puchner.*  
[The figures express percentages of the separates.]

Mineral constituent.	1. Heavy loam.				2. Loamy loess soil.				3. Coarse sandy gneiss soil.			
	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.
CaO.....	Tr.	Tr.	0.04	Tr.	7.23	6.28	4.09	3.39	2.55	1.18	2.23	2.44
MgO.....	0.39	1.42	1.08	0.15	2.41	2.08	1.45	1.19	0.31	.42	.81	.32
K <sub>2</sub> O.....	4.14	1.02	.12	.01	.81	.70	.67	.56	.08	.05	.04	.06
Na <sub>2</sub> O.....	2.35	2.29	2.01	1.18	3.25	3.05	3.02	2.48	3.05	2.94	1.43	1.22
Fe <sub>2</sub> O <sub>3</sub> .....	2.49	5.14	8.95	12.50	3.77	4.98	6.86	9.85	5.38	7.20	9.23	11.11
Al <sub>2</sub> O <sub>3</sub> .....	1.63	15.20	20.48	27.76	7.28	14.20	19.41	29.97	18.71	24.20	30.21	32.42
Mn <sub>2</sub> O <sub>4</sub> .....	Tr.	.70	1.10	3.65	1.54	1.88	1.94	2.79	1.56	1.74	2.48	3.10
P <sub>2</sub> O <sub>5</sub> .....	.03	.08	.08	.19	.15	.12	.17	.03	.06	.03	.05	.04
SiO <sub>2</sub> .....	87.51	72.08	63.22	51.01	71.45	63.95	59.40	50.23	58.00	61.70	52.22	46.54
Humus.....	74	1.48	2.00	3.32	.11	.76	.89	1.97	.23	.59	1.40	2.81

TABLE IV.—*The P<sub>2</sub>O<sub>5</sub>, CaO, MgO, and K<sub>2</sub>O, in the separates analyzed by Puchner, calculated to percentages of the total soil.*

Mineral constituent.	1. Heavy loam.				2. Loamy loess soil.				3. Coarse sandy gneiss soil.			
	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.
P <sub>2</sub> O <sub>5</sub> .....	0.02	0.03	Tr.	0.02	0.10	0.03	Tr.	Tr.	0.01	0.01	Tr.	Tr.
CaO.....	Tr.	Tr.	Tr.	Tr.	4.67	1.63	0.04	0.23	.43	.27	6.11	0.13
MgO.....	.20	.46	Tr.	.01	1.56	.54	.01	.08	.05	.10	.04	.02
K <sub>2</sub> O.....	2.08	.33	Tr.	Tr.	.52	.18	.01	.04	.01	.01	Tr.	Tr.

<sup>a</sup> Landw. Vers.-Stat. 66, 463 (1907).



From the results Puchner draws the conclusion that as the mechanical separates become finer the content of silicic acid, soda, and potash diminishes. On the contrary, that of alumina, iron, manganese, and humus increases. The content of lime, magnesia, and phosphoric acid in the separates is irregular.

Alway and McDale<sup>a</sup> conclude from their study of the distribution of carbonates in the till of the second steppe of the northern Great Plains region that the carbonates are chiefly present in the grains of intermediate size; i. e., the silt particles running from 0.05 to 0.005 mm. in diameter.

Clerk, Gortner, and Vail,<sup>b</sup> working upon a sample of bowlder clay representing the upper 6 feet, made four mechanical fractions—sand, 1.0 to 0.05 mm.; coarse silt, 0.05 to 0.016 mm.; fine silt, 0.016 to 0.005 mm.; clay, smaller than 0.005 mm. These fractions were analyzed chemically by digestion in hydrochloric acid and the determination of the dissolved substances.

In this soil the lime, as carbonate for most part, formed the highest percentage in the silts and least in the clay; the iron, alumina, soda, potash, and phosphoric acid were in greater proportions in the finer fractions; the silts contained the highest percentage of magnesia and the clay the next.

In addition to the investigations mentioned above, numerous chemical and mechanical analyses of the same soil have been made. From the published results of this work one could make comparisons of the total percentages of the several chemical elements in a soil with its percentage content of any particular mechanical component. For example, it could be determined for each soil whether a high content of calcium goes with a high content of sand, of silt, or of clay; but since the investigators themselves did not study these relations, such purely physical and chemical analyses of soils have not been included in a historical review of the literature of the chemical composition of the mechanical separates of soils.

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<sup>a</sup> Am. Chem. Jour., **37**, 275 (1907).

<sup>b</sup> Am. Chem. Jour., **39**, 163 (1908).

NOTE.—Since the manuscript for this bulletin went to the printer a report of additional work along the line of this investigation has come to hand:

Atterberg (Landw. Vers.-Stat., **69**, 102, 1908), working upon a glacial sand from Kulltorp, made complete analyses of the six groups into which he separated the portion between 0.5 mm. and 0.005 mm. diameter. In the table of results given by them the aluminum is a nearly constant constituent; there is an increase in the percentage of the iron and the calcium as the size of the particles decreases except in the finest portion—that between 0.01 and 0.005 mm.—in which these elements decrease. The potassium and the sodium decrease as the particles become smaller.

## SELECTION OF SOIL SAMPLES.

Our extensive collection of soils from important and well-marked soil types enables us to select samples fully representative of the soils of the country. Accordingly, agricultural soils of known character were selected so as to include those from various geographical sections and from a number of soil provinces. Thus we have taken soils from the Coastal Plains, the Piedmont region, glacial soils, non-glaciated soils of the interior, and those of the arid region, the list comprising 27 soil types. These soil types are fully described in the reports of the Field Operations of the Bureau of Soils and in the Soil Survey Field Book, but since these publications may not be easily accessible to readers of this bulletin, the several types analyzed are described briefly in the proper place. The samples taken for analysis are from the surface soil, but the field characteristics of a type, as well as its agricultural value, are often largely dependent upon the subsoil. The subsoils, therefore, often serve to differentiate one soil type from another. The characteristics of the subsoil should therefore be considered an essential part of the description of a soil type. In view of these facts it is obvious that definite conclusions regarding the productiveness of a soil can not be made from a study of the surface soil alone.

Two hundred gram composite samples of the several soil types were separated into the three grades—sand, silt, and clay. In making these separations the whole of the water was poured into the clay dish and evaporated to dryness. Thus any material which dissolved in the repeated treatment of the soil with water was carried into the clay, and this fact must be considered in comparing the results of the analyses of the separates.

The important mineral nutrients only were determined; that is, phosphorus, potassium, calcium, and magnesium. A complete analysis of the soil separates, so far as these constituents are concerned, was made by fusion methods, so that the total content was obtained, and not simply that which would have been extracted by treatment with acid of some conventional concentration.

In the tables giving the results of the analyses the figures are the percentages of the respective substances in the ignited separates, and thus free from organic matter and water. The aim has been to learn the composition of the strictly mineral matter of the soils. It seems safe to assert, however, that were calculations made on the oven-dried soils there would merely be changes in percentages and no material ones in the order of these, so that conclusions based upon them would be consistent with those based upon the mineral matter, as here given.

## SOILS OF THE COASTAL PLAINS.

The Coastal Plains are made up of unconsolidated gravels, sands, silts, and clays derived in most part from the erosion of the Piedmont Plateau and other inland areas. These materials were mainly deposited on the then ocean floor and have been brought to their present level by the elevation of the land areas.

The character of the soils of the Coastal Plains in a broad way, therefore, depends upon that of the rocks and soils of the Piedmont Plateau, but they are modified by deposits from other sources. Thus in the northern portions glacial material is mixed to some extent with the débris of the disintegrated and more or less decomposed rocks of the plateau. In some instances, streams which rise far inland and drain limestone regions have brought materials not common to most of the Coastal Plains soils. While the soils of this region present many diversities among themselves, due to special circumstances affecting their deposition or subsequent history, they all differ much from the parent rock and have been subjected to excessive weathering and leaching.

In studying soils and the results of their analyses, it should be fully recognized that the soil as now found is a distinct product or entity. Simple crushed rock represents no very important agricultural soil. Plants will grow in certain rock powders if compounds of nitrogen be present, but such a "soil" is nowhere found in extensive areas, except possibly as subsoils, and some subsoils were once real surface soils. Unconsolidated rock material should be called rock and not soil, unless it has been subjected to the processes called weathering, with all the numerous changes implied by the term, including those produced by high and low forms of animal and plant life. The soil depends primarily, in the sense of first cause, upon the rock or the rocks from which it originated. As a first step in soil making, the rocks may disintegrate or be crushed to sand or dust. Mechanical agencies may separate the pulverized rocks into groups according to size of particles and deposit them as beds of sand, silt, or clay; or these may remain together, giving rise to loams. Solution and hydration and other chemical processes may effect changes which in some cases leave many of the original mineral grains; in others, the changes may be so profound that few of the original minerals other than quartz remain. The latter extreme condition is less common than is generally supposed, the original minerals, though undoubtedly present, being in so finely divided a form as to be difficultly recognized. Absorptions taking place in soils and other facts make it probable that new minerals similar, if not identical, to those existing in rocks



are formed in soils in minute particles. A soil will then be best understood when all the factors which have operated to produce it are known; that is, when the whole history of the formation of the soil is known. This must often be inferred from the present character of the soil and the geological history of the region. From these considerations it might be expected that soils formed in one general way, as the Coastal Plains soils have been, would constitute a class by themselves and differ in important particulars from those that have had an entirely different history, as glacial soils, for instance. This subject will be referred to again in comparing groups of soils after the analytical data have been given.

The Coastal Plains soils are mostly light; sands and light sandy loams predominating. Those selected for our work are the Collington sandy loam from New Jersey; Norfolk sand, Norfolk loam, and Leonardtown loam from Maryland; Orangeburg sandy loam from Alabama; Crowley silt loam from Louisiana; Orangeburg fine sandy loam from Texas.

*Collington sandy loam.*—The sample analyzed is from the Salem area, New Jersey, surveyed in 1901. The soil is a loose, coarse, sandy loam. It is of a brown color and frequently contains considerable amounts of gravel. It has resulted from the weathering of the greensand, or glauconite, of New Jersey. The subsoil, which comes within 6 or 8 inches of the surface, is a sticky, tenacious, claylike material, yellowish or greenish in color. Owing to its relations to the greensand deposits, this type differs from the other Coastal Plains soils.

*Norfolk sand.*—The sample of this type analyzed is from Prince George County, Md. The area was surveyed in 1900. This is a coarse to medium orange or yellow sand, having a depth of about 10 inches. The subsoil is coarse to medium, becoming loamy at about 3 feet. It is a common type of soil in the Atlantic and Gulf Coastal Plains. The surface is level to rolling and the soil is well drained.

*Norfolk loam.*—The soil is from the Worcester County area, Maryland, surveyed in 1903, and was mapped as Sassafras sandy loam. This soil is a mellow brown sandy loam to a depth of about 9 inches. The subsoil to 36 inches is a medium to heavy loam, which is often underlain by fine yellow sand. In the area from which the samples were taken it has a slight elevation and is gently rolling. It is usually well drained.

*Leonardtown loam.*—The samples used were collected in the soil survey of St. Mary County, Md., 1900. The soil of this type consists of a yellow silty loam, fine and powdery when dry, but puddling to a plastic mass when thoroughly wet. The subsoil consists of a

brittle mass of interlocking clay lenses, lumps, and fragments, separated by seams and pockets of medium to fine sand. This subsoil is as impervious as clay, owing to its peculiar shinglelike structure. It is an upland soil and is generally slightly rolling.

*Orangeburg sandy loam.*—Samples analyzed are from Montgomery County, Ala., surveyed in 1905. This soil, locally called "red lands," is a brown to reddish-brown light sandy loam, 4 to 15 inches deep, resting on a friable brick-red sandy clay subsoil. The surface is rolling. It is generally well drained, although there is a tendency to form a "plowsole" or "hardpan."

*Crowley silt loam.*—The samples used were taken from samples of soil collected in the survey of Acadia Parish, La., 1903. This type is of variable depth, but usually has a surface soil of about 16 inches. It is of a brown color when wet, but ash gray when dry. It is composed of fine sand and silt, with sufficient clay to render it rather impervious. If stirred when wet it puddles somewhat. This soil is underlain by a clay of mottled brown and yellow color, with brick-red streaks and blotches. The subsoil is highly impervious and the surface level, so that the soil has very poor drainage. The samples analyzed are from level prairies in southern Louisiana.

*Orangeburg fine sandy loam.*—The samples used came from the Nacogdoches area, Texas, survey of 1903. This soil varies in color, being red, brown, or gray. It is a light sandy loam, generally carrying iron concretions. The subsoil is a red, friable, sandy clay. The type occupies the upland and has good natural drainage.

The percentage of the several mechanical constituents—sand, silt, and clay—contained in the soils is given in Table V. The results of the chemical analyses of the mechanical separates for phosphoric acid, lime, magnesia, and potash are given in Tables VI and VII. In Table VI the figures express percentages of the separates; in Table VII the percentages are calculated on the whole soil, so that the figures show what percentage the constituent in a separate is of the soil of which the separate is a part.

An inspection of Table VI shows that the elements determined—phosphorus, calcium, magnesium, and potassium—are more abundant in the finer particles of these old soils—old in the sense of having passed through and being the result of all the stages of soil formation.

As shown in Table VII, the coarse particles often contain absolutely more of the elements than the finer portions, but this, of course, is due to the presence in the soil of a much greater percentage of these large particles.

TABLE V.—*Mechanical composition of the Coastal Plains soils.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
	Per cent.	Per cent.	Per cent.
Collington sandy loam, New Jersey.....	78.5	14	6.5
Norfolk sand, Maryland.....	85.5	10	4
Norfolk loam, Maryland.....	64.5	25.5	9
Leonardtown loam, Maryland.....	29.5	55	15
Orangeburg sandy loam, Alabama.....	71	16	12
Crowley silt loam, Louisiana.....	15	59	26
Orangeburg fine sandy loam, Texas.....	69	22	9

TABLE VI.—*Partial chemical composition of the separates of the Coastal Plains soils.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Collington sandy loam, New Jersey.....	<i>P. ct.</i> 0.01	<i>P. ct.</i> 0.09	<i>P. ct.</i> 0.13	<i>P. ct.</i> 0.06	<i>P. ct.</i> 0.30	<i>P. ct.</i> 0.40	<i>P. ct.</i> 0.18	<i>P. ct.</i> 0.22	<i>P. ct.</i> 0.66	<i>P. ct.</i> 0.49	<i>P. ct.</i> 1.86	<i>P. ct.</i> 2.25
Norfolk sand, Maryland..	.01	.10	.94	.07	.27	.98	.19	.11	.48	.33	2.38	2.35
Norfolk loam, Maryland..	.01	.06	.42	.09	.23	1.30	.02	.19	.48	.44	1.49	1.39
Leonardtown loam, Mary- land.....	.01	.02	.03	.04	.08	.13	.07	.25	.87	.56	1.20	1.88
Orangeburg sandy loam, Alabama.....	.01	.21	.21	.03	.19	.24	.01	.11	.14	.05	.96	1.48
Crowley silt loam, Louisi- ana.....	.08	.08	.32	.11	.16	.29	.09	.05	.97	.51	.80	1.47
Orangeburg fine sandy loam, Texas.....	.07	.12	.36	.10	.09	.54	.04	.06	.70	.21	.66	1.50

TABLE VII.—*The content of the separates of the Coastal Plains soils calculated on the whole soil.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Collington sandy loam, New Jersey.....	<i>P. ct.</i> 0.01	<i>P. ct.</i> 0.01	<i>P. ct.</i> 0.01	<i>P. ct.</i> 0.05	<i>P. ct.</i> 0.04	<i>P. ct.</i> 0.03	<i>P. ct.</i> 0.06	<i>P. ct.</i> 0.03	<i>P. ct.</i> 0.04	<i>P. ct.</i> 0.38	<i>P. ct.</i> 0.26	<i>P. ct.</i> 0.15
Norfolk sand, Maryland..	.01	.01	.04	.06	.03	.04	.16	.01	.02	.28	.23	.09
Norfolk loam, Maryland..	.01	.02	.04	.06	.06	.12	.01	.05	.04	.28	.38	.13
Leonardtown loam, Mary- land.....	.01	.01	.01	.01	.04	.02	.02	.14	.13	.17	.66	.28
Orangeburg sandy loam, Alabama.....	.01	.03	.02	.02	.03	.03	.01	.02	.02	.04	.07	.17
Crowley silt loam, Louisi- ana.....	.01	.05	.08	.02	.10	.07	.01	.03	.25	.07	.48	.37
Orangeburg fine sandy loam, Texas.....	.05	.03	.03	.07	.02	.05	.03	.01	.06	.14	.15	.13

## SOILS FROM CRYSTALLINE AND METAMORPHIC ROCKS.

Three soils, not of glacial origin, formed from crystalline and metamorphic rocks, were selected for this work—Chester mica loam (Maryland), Porters black loam (Virginia), and Cecil clay (North Carolina.)

*Chester mica loam.*—Described as Cecil mica loam in the report of the Soil Survey of Harford County, Md., 1901. This soil, as its name indicates, is characterized by a great quantity of micaceous particles. It is derived from granites, gneisses, and other micaceous

rocks over which the type lies. It is strictly a residual soil and consists of a brownish loam 10 to 15 inches deep, underlain by a lighter colored, heavier loam, also containing mica. The surface varies from gently rolling to somewhat hilly.

*Porters black loam.*—The sample analyzed was collected in the soil survey of the Albemarle area, Virginia, 1902. The soil of this type is a loose, mellow black loam, averaging about 12 inches deep. The subsoil is slightly heavier and of a light-brown to yellowish color. In depressions and coves, where wash from the higher ground has accumulated, there is no sharp distinction between soil and subsoil, the loose black loam being several feet deep. Both soil and subsoil contain fragments of the rocks whose decomposition has formed the soil—granites, gneisses, and schists. This type occurs principally in the coves of the Blue Ridge Mountains, but is also found upon the tops and upper slopes.

*Cecil clay.*—The samples of this type were collected near Statesville, N. C., in the survey of that area in 1901. This type is found on uplands, gentle slopes, and rolling lands of the Piedmont Plateau. The Cecil clay is a residual soil, resulting from the disintegration of a number of rocks, differing in mineralogical characters. Granites, gneisses, schists, and other somewhat similar rocks have contributed to the formation of this type, and so thorough have been the disintegration and decomposition that the same red clay results from all. There is such a gradual change from soil to the parent rock that there is generally no sharp line between the two. The soil consists of a heavy red loam, containing many sand grains of the original minerals forming the rocks from which the soil is derived. It is shallow, averaging about 5 inches. The subsoil is a stiff, tenacious red clay to a depth of 3 or more feet. It becomes heavier at greater depths. Natural drainage is fairly good, probably due to the sand and rock fragments contained in soil and subsoil.

The mechanical composition and the results of the analyses of the separates of these soils are given in Tables VIII, IX, and X.

With few exceptions the percentage of the several mineral plant-food constituents increases as the size of the particles of the separates decreases. Chester mica loam, however, which contains many micaeous scales, shows a nearly constant percentage content of lime and magnesia in its separates, while Cecil clay shows the reverse order as to the potash content, the sand being richest in potash, the silt slightly poorer, and the clay decidedly the poorest of the three. While there are some notable exceptions, the absolute quantities are generally fairly evenly distributed in the mechanical components of these soils, as shown in Table X.



TABLE VIII.—*Mechanical composition of the residual soils formed from crystalline and metamorphic rocks.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Chester mica loam, Maryland.....	36	33	30
Porters black loam, Virginia.....	53	23	24
Cecil clay, North Carolina.....	58	17	24

TABLE IX.—*Partial chemical composition of the separates of soils formed from crystalline and metamorphic rocks.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Chester mica loam, Maryland.....	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
Porters black loam, Virginia.....	0.04	0.06	0.33	0.22	0.24	0.28	0.96	0.81	0.88	1.44	2.56	2.55
Cecil clay, North Carolina.....	.15	.53	1.36	1.20	2.07	2.30	.33	1.37	2.28	1.86	3.10	5.06
	.03	.06	.32	.08	.15	.23	.16	.40	.55	1.49	1.45	.97

TABLE X.—*Content of the separates of residual soils from crystalline and metamorphic rocks, calculated on the whole soil.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Chester mica loam, Maryland.....	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
Porters black loam, Virginia.....	0.01	0.02	0.08	0.08	0.07	0.07	0.34	0.25	0.23	0.51	0.79	0.68
Cecil clay, North Carolina.....	.08	.12	.33	.64	.47	.55	.17	.31	.55	.99	.70	1.21
	.02	.01	.08	.05	.03	.06	.09	.07	.13	.87	.25	.24

## SOILS OF GLACIAL ORIGIN.

The group of soils of glacial origin includes soils formed from material deposited by glaciers or this material somewhat reworked by water, and also loessial soils, consisting largely of particles the size of silt, which have been carried from other glacial areas and deposited over the underlying material. The transporting agents in this case were wind and water.

The mechanical composition is given in Table XI; the results of the chemical examination are given in Tables XII and XIII, calculated as before upon the separates and the soils, respectively.

*Podunk fine sandy loam.*—The sample for analysis was taken from a large sample from a very sandy phase of the type found in the Connecticut Valley. The area was surveyed in 1903. This is an alluvial soil, formed by the reworking by running water of glaciated granites, gneisses, and schists. It contains an abundance of micaeous mineral particles visible to the eye. It is underlain by fine sand. The soil is of a dark-brown color and is well drained. The

tobacco field from which the sample came had been heavily fertilized for years.

*Miami sand*.—From the Toledo area, Ohio, surveyed in 1902. The soil is a coarse to medium loose and deep yellowish sand. It is underlain by a yellow sand of about the same texture. It is level to rolling and consists of glacial material somewhat modified by wind action. It occupies elevated positions and is well drained.

*Wabash loam*.—Described as Miami loam in the Report of the Soil Survey of the Toledo Area, Ohio, 1902. This is a dark-brown to black soil of good depth, and containing a small proportion of the coarser grades of sand. The subsoil is a heavy brownish-yellow loam overlying a fine gravelly loam. It is a bottom land, frequently occurring as terraces. It is generally well drained. It consists of glacial drift redeposited by stream action.

*Volusia silt loam*.—The sample for analysis was collected in the soil survey of the Wooster area, Ohio, 1904. This soil is a gray to brown silty loam with an average depth of 8 inches. The subsoil is a light-yellow silty loam, mottled with gray in its lower portions. It has resulted in most part from the glaciation of shales. Its mechanical constituents closely resemble in size those of the soils derived from the loess, being composed largely of silt. This is doubtless due to the silt in the shales from which this soil type comes in large part.

*Marshall loam*.—From samples of this type collected during the survey of the Marshall area, Minnesota, 1903. The surface soil is a somewhat heavy loam from 10 to 12 inches in depth and of a dark-brown color. Under this is a stiff, sticky yellow subsoil to a depth of about 3 feet. Below this is a stiff boulder clay, mottled yellow and gray. The type is generally rolling and well drained. Boulders and glacial gravel occur to some extent over this soil.

*Miami silt loam*.—Described as Edgerton silt loam in the Report of the Soil Survey of the Janesville Area, Wisconsin, 1902. The soil is a very silty loam, light brown when wet and light gray when dry. Its depth is about 8 inches. It is underlain by several feet of stiff, yellow, silty clay that is always mottled with gray, showing poor drainage and aeration. This type originally consisted mainly of timber lands and oak openings.

*Marshall silt loam*.—Described as Janesville silt loam in the Report of the Janesville Area, Wisconsin, 1902. The soil is a mealy, chocolate-colored silt loam with a dark-brown tint when moist. It contains a large amount of silt and becomes somewhat sticky when wet. It is about 10 inches deep. The subsoil is a sticky, reddish-yellow silty clay, about 3 feet deep, and rests upon a glacial gravel or the disintegrating limestone of the region. The soil probably owes some of its distinguishing characteristics to the influence of this limestone.



The type is rolling and well drained. It was originally covered with the prairie grasses of the region.

*Marshall black clay loam.*—Samples collected in the survey of McLean County, Ill., 1903. This soil is a heavy, somewhat sticky granular clay loam, containing a large percentage of silt and organic matter. It has a depth of about 18 inches. The subsoil is a mottled yellow or drab-colored sticky, silty clay. This soil type has formed where the natural drainage was poor. The surface is level. In its original condition it was wet and swampy and required thorough drainage.

*Marion silt loam.*—Samples from Clay County, Ill. The area was surveyed in 1902. The Marion silt loam consists of a light-brown to whitish very silty loam, containing very little organic matter. Its depth averages 12 inches. The soil cakes on drying, but breaks down into flour-like dust when pulverized. The subsoil is heavier and contains more clay. It is so impervious to water as to be locally called hardpan. The lower subsoil is a hard, silty, mottled yellow clay, often containing iron concretions. Below 4 or 5 feet more or less glacial gravel is found. The type is level or slightly rolling. The soil has very poor natural drainage, owing to the rather impervious subsoil and the level surface. While of loessial origin, this soil has been largely formed from sandstones and shales ground up by glaciers.

*Shelby silt loam.*—The sample analyzed was collected in the soil survey of Shelby County, Mo., 1903. The Shelby silt loam is a silty soil of medium depth and of a light-gray color when dry; dark gray when wet. It grades into a stiff, impervious silty clay, plastic and waxy when wet, friable and loamy when dry. The subsoil is a dark mottled clay. It is level or gently rolling. The original growth on this type of soil was the prairie grasses.

TABLE XI.—*Mechanical composition of the glacial soils.*

Soil type and location.	2 to 0.05	0.05 to	0.005 to 0
	mm. (sand).	0.005mm. (silt).	mm. (clay).
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Podunk fine sandy loam, Connecticut .....	80.5	18	2
Miami sand, Ohio .....	91.5	5.5	3.5
Wabash loam, Ohio .....	50.5	38	12
Volusia silt loam, Ohio .....	17	64	19
Marshall loam, Minnesota .....	48	38	13
Miami silt loam, Wisconsin .....	14	72	14
Marshall silt loam, Wisconsin .....	12	70	17
Marshall black clay loam, Illinois .....	21.5	57.5	20
Marion silt loam, Illinois .....	13	69	18
Shelby silt loam, Missouri .....	7	74	19

TABLE XII.—*Partial chemical composition of separates of the glacial soils.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Podunk fine sandy loam, Connecticut	<i>P. ct.</i> 0.12	<i>P. ct.</i> 0.31	<i>P. ct.</i> 3.36	<i>P. ct.</i> 2.35	<i>P. ct.</i> 1.89	<i>P. ct.</i> 6.22	<i>P. ct.</i> 1.10	<i>P. ct.</i> 1.89	<i>P. ct.</i> 3.96	<i>P. ct.</i> 0.74	<i>P. ct.</i> 3.74	<i>P. ct.</i> 4.70
Miami sand, Ohio	.21	.51	1.52	.83	2.59	2.12	.34	1.21	.75	1.89	2.44	3.98
Wabash loam, Ohio	.11	.19	.40	1.56	1.56	3.98	.42	1.07	1.74	2.24	2.90	4.18
Volusia silt loam, Ohio	.09	.09	.46	.43	.30	.43	.37	.37	1.41	2.11	2.16	2.96
Marshall loam, Minnesota	.18	.19	.37	1.63	1.53	4.02	.61	1.30	1.73	1.97	1.71	1.02
Miami silt loam, Wisconsin	.12	.19	.56	.91	.83	1.37	.57	.50	1.73	2.07	2.44	3.73
Marshall silt loam, Wisconsin	.13	.24	.52	.76	.81	1.20	.46	.75	1.68	1.78	2.41	3.32
Marshall black clay loam, Illinois	.31	.32	.56	3.17	2.50	5.53	1.26	1.29	2.79	1.99	2.39	2.54
Marion silt loam, Illinois	.05	.08	.35	.88	.51	.88	.10	.14	.99	.94	1.44	2.07
Shelby silt loam, Missouri	.19	.16	.49	.41	.44	1.14	.13	.25	1.20	1.50	1.87	2.26

TABLE XIII.—*Content of the separates of the glacial soils calculated to percentages of the whole soil.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Podunk fine sandy loam, Connecticut	<i>P. ct.</i> 0.10	<i>P. ct.</i> 0.05	<i>P. ct.</i> 0.07	<i>P. ct.</i> 1.89	<i>P. ct.</i> 0.33	<i>P. ct.</i> 0.12	<i>P. ct.</i> 0.89	<i>P. ct.</i> 0.33	<i>P. ct.</i> 0.08	<i>P. ct.</i> 0.60	<i>P. ct.</i> 0.66	<i>P. ct.</i> 0.09
Miami sand, Ohio	.19	.03	.05	.76	.14	.07	.31	.07	.03	1.73	.13	.14
Wabash loam, Ohio	.06	.07	.05	.79	.59	.48	.21	.41	.21	1.13	1.10	.50
Volusia silt loam, Ohio	.02	.06	.09	.07	.19	.08	.06	.24	.27	.36	1.38	.56
Marshall loam, Minnesota	.09	.07	.05	.78	.58	.51	.29	.49	.22	.89	.64	.13
Miami silt loam, Wisconsin	.02	.14	.08	.12	.60	.19	.08	.36	.24	.28	1.76	.52
Marshall silt loam, Wisconsin	.02	.17	.09	.09	.57	.20	.06	.52	.29	.21	1.69	.56
Marshall black clay loam, Illinois	.07	.18	.11	.68	1.44	1.11	.27	.74	.56	.43	1.37	.51
Marion silt loam, Illinois	.01	.05	.06	.05	.35	.16	.01	.10	.18	.12	1.00	.37
Shelby silt loam, Missouri	.01	.12	.09	.03	.33	.22	.01	.19	.23	.11	1.38	.43

In general, the finer separates of the soils of this group contain the greater percentages of the several elements determined. The Marshall loam and the Volusia silt loam depart most widely from this rule, but several others do not strictly conform to it. The extreme proportionate richness of the clay of the Podunk fine sandy loam may have some connection with the great quantity of fertilizers that have been applied in the growing of tobacco on the field from which the sample was taken.

As to total content of the elements in the several separates, this is generally determined by the relative quantity of the separates in the soil. Thus in the soils consisting largely of silt, a large part of the phosphorus, calcium, magnesium, and potassium is contained in the silt. In the soils consisting largely of sand, the plant-food constituents are found in greatest quantity in the sand. As shown in Table XIII, the silt of Miami silt loam and of Marshall silt loam contains much more phosphate, lime, magnesia, and potash than is contained in the sand and clay combined. The sand of the Miami sand contains more of these elements than the combined content of the silt and the clay.

## SOILS DERIVED FROM LIMESTONES AND SHALES.

Five soils formed from limestones and shales without glacial agency are included in this comparison—Oswego silt loam from Kansas; Wabash silt loam, Kansas; Hagerstown loam, Tennessee; Hagerstown clay, Kentucky; Houston clay, Alabama.

*Oswego silt loam.*—Described as Oswego loam in the report of soil survey of Parsons area, Kansas, 1903. This soil consists of a dark gray silty loam, varying from very shallow to 10 inches deep, which grades into a stiff clay, becoming more impervious with depth. It becomes hard and compact on drying, but it is easily broken up into a mellow loam if plowed when in proper condition of moisture. This is an upland type and occupies gently rolling prairies. Owing to the topography of the country, the type has good surface drainage. The Oswego silt loam is derived from the weathering of the underlying rock, this usually being shales, with occasional interbedded layers of sandstone and limestone.

*Wabash silt loam.*—The sample analyzed is from Riley County, Kans. The area was surveyed in 1906. The soil varies from 12 to 24 inches in depth and consists of a dark-brown to black heavy silt loam. It is easily cultivated and readily kept in good tilth. The subsoil consists of a compact and rather heavy brown or yellowish silt loam. It occurs as long, narrow tracts in the creek valleys and along the outer edges of the river valleys. The type occupies a rather low position in stream valleys and on gentle slopes. Its surface is nearly level or gently sloping. It forms first bottoms of smaller streams and second bottoms of larger ones. It is well drained naturally. The type has been deposited by water, the surface consisting largely of material washed from the surrounding hills, which are made up of shales and limestones. This wash from the hills is continually adding to the type.

*Hagerstown loam.*—Sample collected in the soil survey of the Pikeville area, Tennessee, 1903. This soil consists of brown or yellowish-brown mellow loam from 9 to 12 inches deep. It is underlain by a yellow to reddish-yellow stiff loam or light clay loam, which becomes a more pronounced red with depth. Traces of chert are found in both soil and subsoil. This type was formed by the slow weathering of limestones. In this soil the weathering has been so complete and the leaching so excessive that the lime of the disintegrated stone has been largely washed from the soil. The type has a moderately rolling surface and has good surface drainage, but the subsoil is rather impervious. The underlying limestone comes near the surface in some places, owing to erosion.

*Hagerstown clay.*—The sample analyzed was collected in the soil survey of Scott County, Ky., 1903. This soil has a heavy texture



and varies from 3 to 12 inches in depth. It is yellow or brown in color. The subsoil is a heavy yellow clay, extending to a depth of 3 or more feet. This soil type is derived from limestones and shales. These rocks offer considerable resistance to disintegration, and the soil may therefore be more thoroughly leached than would be the case were the rocks more readily decomposed. The surface is rather rough, rounded hills being dominant features. Surface washing has been great, and the soil is generally shallow, the depth depending on its position. This is a residual soil, being formed from the breaking down in place of the underlying limestones and shales.

*Houston clay.*—The sample is from Dallas County, Ala. The area was surveyed in 1905. Although this type is really a Coastal Plains soil in so far as its mode of occurrence is concerned, it is here grouped with the limestone soils. It has resulted from the weathering of rotten limestones or chalks of Cretaceous time. Owing to its proximity to the soft and easily broken down lime rock, this soil is highly calcareous, and often contains lime concretions, especially in the subsoil. It may be considered to be of comparatively recent origin and as a residual Coastal Plains soil. The soil is a gray, brown, or black loamy clay, 6 inches deep. This is underlain with 3 or more feet of heavy gray or mottled yellow clay. The surface is gently rolling and the drainage very good. Agriculturally the soil is lighter than would be expected from its high clay content. This may be due to flocculation by the high percentage of lime present.

Table XIV shows the mechanical composition of the soils of this group. Tables XV and XVI give the results of the chemical examinations.

TABLE XIV.—*Mechanical composition of the soils formed from limestones and shales.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005mm. (silt).	0.005 to 0 mm. (clay).
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Oswego silt loam, Kansas.....	25	57	18
Wabash silt loam, Kansas.....	13	69	18
Hagerstown loam, Tennessee.....	36	40	23
Hagerstown clay, Kentucky.....	7	48	46
Houston clay, Alabama.....	28.5	25.5	46.5

TABLE XV.—*Partial chemical composition of the separates of limestone and shale soils.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Oswego silt loam, Kansas.....	<i>P. ct.</i> 0.07	<i>P. ct.</i> 0.08	<i>P. ct.</i> 0.31	<i>P. ct.</i> 0.19	<i>P. ct.</i> 0.33	<i>P. ct.</i> 0.93	<i>P. ct.</i> 0.06	<i>P. ct.</i> 0.13	<i>P. ct.</i> 1.54	<i>P. ct.</i> 0.64	<i>P. ct.</i> 1.31	<i>P. ct.</i> 1.88
Wabash silt loam, Kansas.....	.05	.07	.40	.81	.88	2.67	.30	.43	2.16	2.27	2.96	3.64
Hagerstown loam, Tennessee.....	.04	.05	.40	.22	.26	.94	.19	.30	1.60	.12	.84	1.68
Hagerstown clay, Kentucky.....	.32	.28	.55	7.81	3.12	2.37	.76	.87	2.82	3.48	3.60	5.07
Houston clay, Alabama.....	.48	.36	.77	28.73	29.51	26.45	.87	.88	1.60	.79	1.05	1.10

TABLE XVI.—*Content of the separates of the limestone and shale soils calculated to percentages of the whole soil.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
Oswego silt loam, Kansas.	0.02	0.05	0.05	0.05	0.19	0.16	0.02	0.07	0.27	0.16	0.75	0.33
Wabash silt loam, Kansas.	.01	.05	.07	.10	.60	.48	.04	.29	.88	.29	2.03	.65
Hagerstown loam, Tennessee.	.01	.02	.09	.08	.10	.22	.07	.12	.37	.04	.34	.39
Hagerstown clay, Kentucky.	.02	.13	.25	.55	1.50	1.09	.05	.42	1.07	.24	1.73	2.33
Houston clay, Alabama.	.14	.09	.36	8.19	7.53	12.30	.25	.22	.74	.23	.27	.51

Excepting the lime and the phosphates in the calcareous soils, Hagerstown clay of Kentucky and Houston clay of Alabama, these limestone and shale soils follow the rule that the finer the separate the greater the percentage of the four elements determined. In the cases of high lime content there may be calcium carbonate in the form of sand as that term is here used, and quartz and other sands may be coated with carbonate of lime. In the clay soils the greatest absolute quantity of lime is contained in the clays; in the loams the silts often have greater quantity.

The Oswego silt loam and the Hagerstown loam are in marked contrast with the clays in that the latter contain larger percentages of the several elements determined, notably the potash in Hagerstown clay, the lime in Houston clay, and the phosphoric acid in both. This comparative poverty in the former is doubtless due in part to these soils being the result of more extended weathering than are the two clays, and the rocks from which they are formed differ considerably.

While the separates of any one of these shale and limestone soils can be compared among themselves, no useful comparison of one of the soils with another can be made unless the full history of the soils be considered. Some of them have come from shales with layers of interbedded limestones, others from massive limestones, and the extent of weathering and leaching has varied so that a similar soil could not result. Notwithstanding this, the plant-food constituents are concentrated in the finer separates of all these shale and limestone soils as in those of greatly different origin.

Not only are the finer separates of this group of soils richer in plant-food constituents as determined by percentage composition, but since the soils are mainly clay and silt the absolute quantities, as shown by Table XVI, are greater in these portions.

## SOILS OF THE ARID REGIONS.

Two soils formed under arid conditions, or at least that have been under arid conditions for very long periods, were used in this work—one from the Fresno series and one from the Indio series.

*Fresno fine sandy loam.*—Described as Fresno sandy loam in the report of the soil survey of the Fresno area, California, 1900. This soil is composed largely of silt to fine sand. It is locally known as "white-ash land," from its color and its physical character. The soil has probably been derived from volcanic ash, but light-colored loams and sands have also contributed to it. The soil lies flat and works well, unless it be puddled, when water penetrates it slowly and hard clods or lumps form on drying. The lower subsoil is heavier, a blue clay being encountered at the depth of a few feet. Because of poor drainage or light rainfall this soil generally contains alkali.

*Indio fine sandy loam.*—Described as Fresno sandy loam in the report of the soil survey of the Indio area, California, 1903. This soil is made up of clay, silt, and the finer grades of sand. The clay is so flocculated that the soil in its field condition is lighter than the mechanical composition would indicate. The soil was mainly formed by erosion from adjacent mountains, the material being deposited in a bay or arm of the sea, but it has been greatly modified by wind action. It contains micaceous grains and minute shells. The soil ranges in depth from  $2\frac{1}{2}$  to 5 feet and is underlain with sandy loam or sand. The surface usually has a uniform slope and is generally well drained, but its high capillary power draws much water to the surface, causing an accumulation of alkali by its evaporation. In the lower levels the alkali is present in injurious amounts. Owing to insufficient rainfall the salts are not washed out of this soil so well as might be expected from its physical character.

Tables XVII, XVIII, and XIX give the mechanical composition and the results of the analysis of the separates of these soils. .

Table XVIII would show these two soils to be somewhat similar to those of humid regions in respect to the distribution of the elements in the mechanical separates. Excepting the lime in the highly calcareous Indio fine sandy loam, the finer the separates, in general, the higher the percentage of the elements determined, and of course the less siliceous they are. Since these soils contain considerable alkali or water-soluble salts, constituents which would here appear in the clay, the content of the clay proper would be somewhat less than shown in the tables. In the case of the potash it would probably be considerably less. It will be observed that the sand of the Indio fine sandy loam contains slightly more potash than the silt. Were the apparent content of potash in the clay reduced by that which has been washed from the whole bulk of soil and concentrated in the clay, thus obtaining that of the clay itself, this true content would probably not greatly exceed that of the sand. Were the same correction made for the Fresno fine sandy loam, the clay would be about like the silt in potash content. The same considerations apply to the other elements, but doubtless to a less degree; but after mak-



ing due allowance for this source of error, it would appear that the coarser particles are somewhat poorer in phosphorus, magnesium, and potassium.

TABLE XVII.—*Mechanical composition of the arid soils.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
Fresno fine sandy loam, California.....	<i>Per cent.</i> 66.5	<i>Per cent.</i> 25.5	<i>Per cent.</i> 8
Indio fine sandy loam, California.....	46	29	24

TABLE XVIII.—*Partial chemical composition of the separates of the arid soils.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Fresno fine sandy loam, California.....	<i>P. ct.</i> 0.15	<i>P. ct.</i> 0.22	<i>P. ct.</i> 0.65	<i>P. ct.</i> 3.16	<i>P. ct.</i> 3.55	<i>P. ct.</i> 6.20	<i>P. ct.</i> 0.78	<i>P. ct.</i> 1.81	<i>P. ct.</i> 5.85	<i>P. ct.</i> 3.26	<i>P. ct.</i> 5.58	<i>P. ct.</i> 6.27
Indio fine sandy loam, California.....	.22	.27	.25	15.02	14.89	9.87	2.20	4.14	4.82	2.84	2.73	3.86

TABLE XIX.—*Content of the separates of arid soils calculated to percentages of the whole soil.*

Soil type and location.	P <sub>2</sub> O <sub>5</sub> .			CaO.			MgO.			K <sub>2</sub> O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
Fresno fine sandy loam, California.....	<i>P. ct.</i> 0.10	<i>P. ct.</i> 0.06	<i>P. ct.</i> 0.05	<i>P. ct.</i> 2.10	<i>P. ct.</i> 0.91	<i>P. ct.</i> 0.50	<i>P. ct.</i> 0.52	<i>P. ct.</i> 0.46	<i>P. ct.</i> 0.47	<i>P. ct.</i> 0.17	<i>P. ct.</i> 1.42	<i>P. ct.</i> 0.50
Indio fine sandy loam, California.....	.10	.08	.06	6.94	4.35	2.36	1.02	1.21	1.15	1.30	.80	.92

## COMPARISONS OF THE GROUPS OF SOILS.

It is interesting to compare the soils of one province with those of another. If the soils of the Coastal Plains be compared with those of the Piedmont Plateau and of the Appalachian Mountains, certain distinct differences are observed. The latter soils are residual—that is, they have been formed where now found or have been moved but short distances. The method of formation, in addition to pulverization, has been one of removal of certain parts of the rocks, either by solution or, mechanically, by moving water or air, leaving the present soil as a residue. The material forming the soil may differ but little chemically and mineralogically from the rocks whose breaking down has produced the soil, or it may depart much from them. An illustration of the latter is seen in the clays resulting from limestones.

The soils of the Piedmont used in this investigation contain abundant fragments of the original minerals undecomposed. The Coastal Plains soils have resulted to a large extent from material washed from the Piedmont Plateau and deposited in water at lower levels.

They have suffered from decomposition and solution more than have the Piedmont and Appalachian soils, and there has often been a greater separation of the finer from the coarser particles.

The tables show that the residual soils, Chester mica loam, Porters black loam, and Cecil clay, contain more plant-food constituents than do the Coastal Plains soils. This is especially true of the phosphorus, the potassium, and the magnesium. It is in the coarser materials, the sands, where the greatest difference in composition is found. In the sands of the residual soils the potash averages 1.60 per cent, in the sands of the Coastal Plains soils the potash averages 0.37 per cent, the sands of the residual soils being over four times as rich. In the clays the averages are, respectively, 2.86 per cent and 1.79 per cent, the clays of the residual soils being about one and a half times as rich as those of the Coastal Plains soils. A comparison of the potash content of the sand of a soil with that of the clay of the same soil shows that relatively as well as absolutely the sands of the residual soils are richer than those of the Coastal Plains. For example, in the Norfolk loam and the Crowley silt loam, having the least difference in the potash content of the sand and the clay of any of these Coastal Plains soils, the clay is three times as rich as the sand. In the Orangeburg fine sandy loam the content of potash in the clay is seven times that in the sand. In the Orangeburg sandy loam the ratio is 30 to 1. In the residual soils, on the other hand, the ratios are smaller, being 2.7 to 1 in Porters black loam, 1.8 to 1 in Chester mica loam, and 0.7 to 1 in Cecil clay. A similar comparison for the other elements will lead to the same conclusion—that the clays and the sands of the Coastal Plains soils differ more in composition than do those of residual soils.

The glacial soils consist largely of crushed rocks. Much of the material composing them has not been profoundly weathered. They are therefore quite similar in composition to the residual soils, and hence differ from those of the Coastal Plains. A comparison of the composition of the separates of glacial, residual, and Coastal Plains soils shows this. It is true of all constituents, unless it be phosphorus. If, as before, the potash content be taken for comparison, it is seen that the clays of the glacial and the residual soils contain about twice the percentage that the sands do, while the potash content of the clays of the Coastal Plains soils is five times that of the sands.

The sandy and the silty glacial soils are somewhat similar in percentage composition. Owing to the latter consisting to so large an extent of such fine particles, it might have been supposed that decomposition and leaching would have affected them more, and that there

would have been a greater difference between the two classes than the figures show. The average potash content of the silty soils is slightly greater than that of the others, as may be determined from the table, being 2.16 per cent and 1.94 per cent, respectively. The magnesia is 0.74 per cent of the silty soils and 0.86 of the others; the lime, 1.08 per cent and 1.76 per cent; the phosphoric acid, 0.23 per cent and 0.22 per cent, the figures being in all cases averages calculated from the table. But the silty soils are loessial for the most part and were formed from material blown by winds from glaciated areas and deposited where now found, or of material that has since been reworked by water. Minerals rich in alkalies and alkaline earths, being relatively easily crushed, would form a larger percentage of these silty soils than they do of the original glacial soils; so that even if there has been a tendency to impoverish them by leaching, their originally greater richness enables the loessial soils to compare well with those strictly glacial.

We have but two soils of the arid region to compare with the twenty-five of humid regions. The latter were selected to represent soils of all classes—those of low, of medium, and of high productivity; sandy soils, clay soils, calcareous soils, and those intermediate between these several extremes. They may be taken as fairly well representing the humid soils. The two arid soils can not be considered to represent so well those of the region because of their limited number and similarity of texture, both being fine sandy loams.

If the separates of these arid soils be compared with those of soils that have been profoundly weathered and leached, such as the Coastal Plains soils and the shale soils, it will be found that the coarser separates of the former are richer relatively than the finer ones. If a like comparison be made of the arid soils with the glacial soils, the residual soils, and the calcareous soils, they are all found to be quite similar in so far as the distribution of nutrients among the separates is concerned.

It should be noted that our comparison of arid soils with those of humid regions is in no way similar to that made by Tolman (p. 10). He compared the solubility of the separates rather than their composition. It is well known that sands are often coated with colored iron compounds, so that what is called a yellow or a red sand becomes transparent, colorless quartz sand when treated with acid. Other minerals in the form of sand are also similarly coated. The finer portions, the silts and the clays, are often the most highly colored. It is generally impossible to tell whether the coloring compounds are simply finely pulverized and mixed with the silt and the clay, or whether the colors exist in the form of thin coatings on

the grains of these materials. Schloesing<sup>a</sup> believes the latter to be largely the case. It seems reasonable to believe that the slightly soluble compounds existing in soils, such as the carbonates and the phosphates of the alkaline earths, the phosphates of iron and aluminum, the more soluble silicates and silico-aluminates, etc., may form coatings on minerals just as do the oxides and the hydroxides of iron. If the minerals or their decomposition products had been in solution and then separated out because of concentration of the solution by evaporation, the deposition would be on the grains. Even if the adhesive force were equal over surfaces of large and of small grains, so that the films would be of equal thickness, there would be a larger percentage in the coatings of small particles, since in these the surfaces exposed are much greater in proportion to mass. There would be a tendency for this coating film to thicken, for on the assumption of a surface attraction, it would be from the reserves of these slightly soluble substances and not from the films that more of the material would go into solution when water is added to the soil by rain or otherwise. The deposition would take place over the previous film as the soil becomes drier again. At length the action would be in equilibrium when the tendency to dissolve from the films and from the reserves is equal. While this is probably one of the reasons for the greater percentage of acid-soluble substances in the finer separates, it can hardly be doubted that because of their softness in comparison with such minerals as quartz the compounds containing the nutrients are more finely pulverized in soil making, and that they are therefore more largely reduced to the size of silt and clay. In arid regions this solution and deposition would not take place to so large an extent, since the soils are seldom thoroughly wet. Decomposition or alteration taking place on the surfaces of mineral grains, the latter would remain coated with decomposition products if there were lack of water to remove the coating or to continue the kaolinization process further. The coarser grains of soils are more likely to be thus coated in arid regions than in humid ones. The decomposition products being more soluble in acid than the original minerals, it may frequently happen that the sands of arid soils yield more material to the acid used in analysis than do the sands of humid soils, and for the reason given above. Tolman<sup>b</sup> believes this to be a general fact, and suggests the above explanation of it.

While the existence or nonexistence of these unremoved coatings of decomposition products would account for differences in the solu-

<sup>a</sup> Compt. Rend., **135**, 601-605 (1902).

<sup>b</sup> Rept. Agr. Expt. Sta., Univ. Cal., 1898-1901, p. 40 et seq.



bility of the mechanical separates of soils, they would cause no great difference in composition as shown by fusion methods, for the latter would show the total content of the grains, whether they be partially decomposed or not.

## ROCKS, SOILS, AND SOIL SEPARATES.

Comparisons have often been made of residual soils with the rocks from which they were in large part formed. In many cases this can be done with considerable certainty that the proper materials are being compared. But most of the soils studied in this bulletin are far removed from the rocks whose disintegration produced them, and they are mixtures of such diverse materials that comparisons of the sediments with the parent rock can not be made. It may, however, be of interest to compare the separates of these soils with such well-known rocks as granites, syenites, gneisses, shales, and sandstones. Each of these classes of rocks varies considerably in ultimate composition, depending upon the proportion of their constituent minerals, but by taking several of each class some conception of common limits of variation may be formed. In the following tables the percentages of  $P_2O_5$ , CaO, MgO, and  $K_2O$  in a number of these rocks are given.<sup>a</sup>

TABLE XX.—*Partial composition of granites.*

Type of rock and location.	$P_2O_5$ .	CaO.	MgO.	$K_2O$ .
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Granite, Currant Creek Canyon, Pikes Peak, Colorado.....	0.22	0.58	0.07	6.56
Biotite granite, Sentinel Point, Pikes Peak, Colorado.....	Trace.	.80	.04	4.92
Granite, Currant Creek Canyon, Pikes Peak, Colorado.....	.05	.23	.14	7.99
Biotite granite, Vermont.....	.11	1.13	.33	4.81
Soda granite, Minnesota.....	.20	.66	.58	4.97
Granite, Florissant, Colorado.....	Trace.	.15	Trace.	4.15
Granite, Montana.....	.06	1.26	.35	6.09
Aplite, Sierra County, California.....	.03	1.28	.05	5.18

TABLE XXI.—*Partial composition of trachyte-syenite rocks.*

Type of rock and location.	$P_2O_5$ .	CaO.	MgO.	$K_2O$ .
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Nordmarkite, Vermont.....	0.13	1.49	0.40	5.97
Quartz syenite porphyry, Bearpaw Mountains, Montana.....	.10	1.32	.77	5.76
Biotite trachyte, Dike Mountains, Yellowstone National Park.....	.22	.93	.63	5.47
Soda syenite porphyry, Moccasin Creek, California.....	.11	.55	.24	4.10
Soda syenite, Alaska.....	.06	2.66	.06	3.39
Biotite trachyte, Dike Mountains, Yellowstone National Park.....	.25	2.78	.91	6.11
Augite syenite porphyry, Copper Creek Basin, Yellowstone National Park.....	.21	2.60	1.13	4.56
Augite syenite, Turnback Creek, California.....	.16	5.61	1.69	7.70
Syenite, Little Belt Mountains, Montana.....	.33	4.61	3.67	4.50
Syenite, Colorado.....	.35	3.77	1.24	5.05
Syenite, Crazy Mountains, Montana.....	.26	3.69	1.51	5.34

<sup>a</sup> Clarke. Data of Geochemistry, 368-371, 463, 468, 534-535 (1908).

TABLE XXII.—*Partial composition of gneiss.*

Type of rock and location.	P <sub>2</sub> O <sub>5</sub> .	CaO.	MgO.	K <sub>2</sub> O.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Sedimentary gneiss, Canada .....		0.35	1.81	2.50
Quartz-biotite-garnet gneiss, New York.....	0.11	2.40	2.40	1.93
Mica gneiss, Pennsylvania.....	.22	1.87	2.42	2.86
Gneiss, Maryland.....		9.69	5.98	1.56
Gneiss, sedimentary, Great Falls Potomac.....	.11	1.68	.95	1.35
Biotite gneiss, Michigan.....		1.87	1.26	2.35
Quartz-norite gneiss, Minnesota.....		5.99	3.62	.55

TABLE XXIII.—*Partial composition of sandstones.*

Type of rock and location.	P <sub>2</sub> O <sub>5</sub> .	CaO.	MgO.	K <sub>2</sub> O.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Brown sandstone, Hummelstown, Pa.....		0.20	0.53	2.63
Ferruginous sandstone, Norfolk, England.....	0.42	2.43	.95	.48
From a "Sandstone dyke," Shasta County, Cal.....	.14	16.39	2.22	1.17
Miocene sandstone, Mount Diablo, Cal.....	.29	14.65	5.55	1.37
Composite of 253 sandstones.....	.08	5.32	1.17	1.32
Composite of 371 building sandstones.....	.06	1.05	.52	1.16
Sandstone from Hurley, Wis.....		.70	1.39	1.62

TABLE XXIV.—*Partial composition of shales.*

Type of rock and location.	P <sub>2</sub> O <sub>5</sub> .	CaO.	MgO.	K <sub>2</sub> O.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Composite of 51 Paleozoic shales.....	0.15	1.41	2.32	3.60
Composite of 27 Mesozoic and Cenozoic shales.....	.20	5.96	2.67	2.07
Black Devonian shale, Morenci, Ariz.....	.08	3.40	4.16	6.74
Middle Cambrian shale, Coosa Valley, Alabama.....	.06	1.60	2.32	3.19
Bituminous shale, Dry Gap, Georgia.....	.31	.78	1.15	3.16
Shale near Rush Creek, Colorado.....	.17	12.09	2.12	2.31
Carboniferous shale, Elliott County, Ky.....	.08	9.91	1.91	.88
Cretaceous shale, Mount Diablo, California.....	.08	27.87	2.61	.....

A comparison of the figures in the above tables with those for the separates of the glacial soils in Table XII shows that the phosphates in these rocks and in the sands and silts are of about the same order of magnitude, and that they are appreciably higher in the clays. It would seem, then, that in so far as these soils resulted from rocks like the above there has been little change in the percentage of phosphates in the portions forming sand and silt, while there has been a concentration in the clays. The change of the minerals comprising these rocks to "clay" is a somewhat complex one. In so far as it is chemical it is mainly a loss of alkalis and alkaline earths by solution, and the taking up of water in kaolmization. The first process would tend to increase the proportion of phosphate, the latter to decrease it.

A similar comparison of the lime content shows that, while there is much variation in the percentage of this base, in general the granites are somewhat below and the syenites and gneisses somewhat above the several separates.



The sands and the silts of the glacial soils have much the same magnesia content as the granites and syenites, and the clays are richer. The gneisses contain more magnesia than any of these separates.

A comparison of the potash content shows that the granites and syenites are richer in this element than are any of the sediments—much richer than the sands and the silts. The gneiss rocks are about like the sands and poorer than the silts and clays.

These various relations may have come about by the mixing of the débris of very diverse rocks, those richer in the elements named with those poorer, or by the decomposition and leaching of the broken down richer rocks.

Of the soils formed from crystalline and metamorphic rocks by other than glacial action (pp. 19 to 21) the Chester mica loam and the Cecil clay, as a whole, contain about the same proportion of phosphate as do the granites and gneisses, the sands and silts being low, the clays relatively high. Calcium is a less abundant constituent of the soils than of the rocks. The soils contain about as large a proportion of magnesium as the granites and less than the gneisses. The syenites are variable in the content of this element, some of these rocks being poorer than the two soils and some richer.

Some of the separates of these soils are richer in the elements than the rocks and some poorer. Thus in general the rocks contain a greater percentage of phosphate than the sand and silt separates and less than the clays. All the separates are of lower lime content than the rocks. Their magnesia content is greater than that of the granites and less than that of the gneisses. The potash of the separates is very similar to that of the gneisses, but much less than that of the granites.

Porters black loam more nearly resembles the syenites in composition, and its separates are irregular when compared with the rocks. This soil is said to be derived from granites and gneisses in large part. The content of potash, lime, and magnesia in the whole soil is intermediate between that of the rocks as shown in these tables.

#### SUMMARY.

As a general rule the smaller particles of soils are richer in potassium, calcium, magnesium, and phosphorus than the coarser particles.

The concentration of these elements in the finer components is the more pronounced as the soils have undergone more extreme weathering.

In glacial soils and others resulting largely from mechanical processes the coarser particles are relatively high in the percentages of potash, lime, and magnesia.

The larger mechanical components contain these elements in forms which by protracted weathering will become more soluble, and they will ultimately be concentrated in the finer components.

Calcium is often rather low in clay soils resulting from the weathering of hard, compact limestones. It is generally abundant in soils recently formed from easily broken down limestones. The sands of these latter soils may contain a high percentage of calcium, probably as lime sand or as coatings on other large mineral grains.

A comparison of soils and soil separates with crystalline rocks indicates that in the process of the weathering of these rocks the phosphate remains of about the same proportion or slightly increases. The lime and potash seem to decrease in percentage, although minerals containing them are always present.

## O

